PATENT SPECIFICATION (11) 1 506 305

(21) Application No. 7323/76 (22) Filed 24 Feb. 1976 (19)

(31) Convention Application No. 2 513 467

(32) Filed 26 March 1975 in

(33) Fed. Rep. of Germany (DE)

(44) Complete Specification published 5 April 1978

(51) INT. CL.² A61M 5/14

(52) Index at acceptance

F1R 15A

1 506 305

(54) DEVICE FOR SUPPLYING A HUMAN OR ANIMAL BODY WITH FLUID

(71) We, SIEMENS AKTIENGESELLSCHAFT, a German company, of Berlin and Munich, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a device for supplying a human or animal body with fluid, and is for example applicable to the controlled supply of medicaments, e.g. insulin, to the body.

When treating patients, more particularly with fluid medicaments, a fixed rate of medicament infusion into the body may often be unsuitable, and so the amount of fluid infused per unit time may therefore have to be readjusted at certain intervals. This is particularly the case where insulin is to be continuously infused for diabetotherapy, because the insulin requirement of the diabetic is subject to considerable fluctuations during the day, caused for example by the rhythm of meals, while on the other hand it is more or less constant during the night.

It is accordingly desirable to provide a device, for supplying a human or animal body with fluid, permitting medicament dosage to be finely controlled without undue energy requirements.

According to the present invention, there is provided a device for supplying a human or animal body with fluid, the device comprising: a storage container for the fluid; a fluid delivery system for the delivery of fluid from the container into the body via a fluid outlet; and a pressure generator which acts, without an external energy supply, to exert on fluid in the container a pressure sufficient to cause expulsion of fluid from the container into the body via the delivery system, the pressure generator serving to maintain the fluid pressure in the container continuously greater than the fluid pressure at the fluid outlet; the fluid delivery system including (a) a switchable valve openable by the application of control pulses thereto for the periodic release of fluid from the storage container, and (b) a pulse generator for applying to the switchable valve pulses of a predetermined frequency and/or duration for controlling the rate of the periodic release of fluid thereby controlling the peak rate of fluid supplied to the body; the fluid delivery system further including (a) a first flow limiter for controlling the flow of the fluid periodically released by the switchable valve, and/or (b) an auxiliary store for storing and then releasing a predetermined volume of the fluid periodically released by the switchable valve.

The switchable valve is such that the application of control pulses to the valve opens it so as to allow fluid to pass through a flow path of the valve in successive quantities towards the fluid outlet of the delivery system. A required degree of fine dosaging is achieved by appropriate adjustment of the size of these successive quantities and the repetition rate at which they are allowed to pass through the valve, i.e. by adjustment of how often the relevant flow path through the valve is opened and the duration for which it stays open. These parameters may be determined by a preselected programme by the fact that the flow control valve is arranged to receive control pulses from the pulse generator in accordance with a desired programme. The generator is operable to apply the control pulses at a selectively variable pulse duration so as to bring about delivery of fluid into the body at a correspondingly variable rate. For example, to bring about delivery of fluid into the body at a basic delivery rate the pulse generator may be settable to apply control pulses to the flow control valve at a low repetition rate and, to bring about delivery of fluid into the body at a higher delivery rate, the pulse generator may then also be controllable to adjust the pulse repetition rate and/or the pulse duration of the control pulses.

The pressure generator of a device embodying the invention is one which does not require to be supplied with energy from outside. For example, the generator may comprise a flexible container containing a substance having a superatmospheric vapour

pressure at body temperature, this container being arranged to press against the fluid in the storage container of the device. The vapour pressure of th substance employed may be up to roughly three bars, and the substance contained in the flexible container, this container comprising for example a bellows-form membrane, may for instance be chloroethane, a fluorinated alkane or a fluorinated and chlorinated alkane (e.g. "Freon", registered trade mark).

External energy need only be supplied to a device embodying the invention for the purposes of switching the flow control valve between its different flow conditions. Only a relatively small amount of energy may be required, however, since the switching frequency and/or the switching duration necessary to achieve adequately fine dosaging can be kept relatively small.

For a better understanding of the invention, and to show how it can be carried into effect, reference will now be made, by way of example, to the accompanying diagrammatic drawings, in which:

Figure 1 shows a block circuit diagram of one form of device embodying the invention,

Figures 2 and 3 are pulse diagrams illustrating possible flow control techniques in such a device, and

Figures 4 to 7 respectively show block circuit diagrams of four other forms of device embodying the invention.

The device as shown in Figure 1 has a storage container 1 for storing a fluid medicament, for example insulin. This container may for example have a volume of about 10cm³. The medicament concentration is such that the supply contained in the storage container 1 will be enough for dosing a human or animal patient with the medicament for a period of, say, 100 days to 1 year.

Arranged within part of the storage container 1 is a pressure generator comprising a flexible container 2 constituted by a bellows-form membrane. The flexible container 2 contains a substance which is liquid at room temperature and in the vicinity of the body temperature has a super-atmospheric vapour pressure of up to about 3 bars. At constant temperature, therefore, the pressure generated in the flexible container 2 is independent of the volume of the container. The flexible container 2 thus exerts a constant superatmospheric pressure on the medicament stored in the storage container 1. A suitable substance for the flexible container 2 is for example chloroethane.

The storage container 1 is provided with a refill line 3 fitted with a non-return valve 4 for preventing expulsion of medicament via the line 3. Medicament liquid in the container 1 may be topped up, via the line 3 and the non-return valve 4, by means of a hypodermic syringe 5 for example. In place of the non-return valve 4 a self-sealing mass of plastics material may for example be used. The storage container 1 is also provided with an expulsion line 6 via which medicament can be expelled from the container 1 as the storage volume thereof decreases on account of the pressure exerted by the flexible container 2. By way of a fluid delivery system to be described below, medicament expelled via the line 6 eventually passes to a thin supply catheter 7 arranged to deliver fluid into the blood stream of the patient. The catheter is made of a material which is blood-compatible, for example polyurethane, and is heparinized if necessary. At its outlet end the catheter 7 may also be provided with a safety mechanism to prevent possible inflow of blood.

The above mentioned fluid delivery system comprises an electro-mechanical 2/2-way flow control valve 8 arranged between the expulsion line 6 and the catheter 7. When unenergised, the valve 8 is in a blocking condition preventing communication therethrough between the line 6 and the catheter 7. However, when an electromagnetic actuator 8*a* of the valve 8 is energised, the valve switches into an open condition permitting such communication. Switching of the flow control valve 8 between its blocking and open conditions is controlled by the application of control pulses to the actuator 8*a* from a pulse generator 9. The pulse repetition rate at which the control pulses are supplied, and/or the duration of these pulses, is selectively adjustable in accordance with a presettable programme. Alternate switching of the flow control valve 8 between its blocking and open conditions results in the passage of successive quantities of medicament through the valve towards the supply catheter 7, the size of these quantities being determined by the switching frequency and switching duration.

For controlling the operation of the pulse generator 9, and thus the delivery of medicament into the body, the device shown in Figure 1 is provided with a programme transmitter 10. This programme transmitter includes a control signal emitter 11 (HF-modulated) and a programme store 12 with a timing device (digital clock) and a programme introduction device 13 for introducing time or switching frequency information. The programme transmitter 10 also includes an information transmitter 14 for indicating, for example, the prevailing programme stage and the time. The programme transmitter 10 may also include an optical or acoustic signal transmitter (not shown) for signalling the intake of metals and/or indicating other

stored information, for example the number of bread units to be taken and/or when a quantity of medicament is to be taken by the patient. Energy for the programme transmitter 10 is supplied from a battery 15, control signals from the control signal emitter 11 being transmitted to the pulse generator 9 by virtue of the inductive coupling between an emitter coil 16 on the output side of the transmitter 11 and a receiver coil 17 on the input side of the pulse generator 9.

For further programme control, there is associated with the pulse generator 9 a manually actuable switch 18, e.g. a push-button switch or magnetic switch, which serves as a programme transmitter for the pulse generator 9. The switch 18 may for example serve for the individual correction of a programme, for example in the event of occasional or continuous non-occurence of control signals from the control signal transmitter 11 of the programme transmitter 10.

The fluid delivery system of the device shown in Figure 1 includes a flow limiter 19 (flow resistance) arranged in a flow path between the storage container 1 and the fluid outlet of the delivery system and, in fact, between the flow control valve 8 and the catheter 7. The flow limiter 19 is adjustable so as to permit adjustment of the size of successive quantities of fluid delivered into the body via the flow control valve 8 as control pulses are successively applied thereto from the pulse generator 9, the size of these fluid quantities being dependent also on the duration of the control pulses. In the present case, the flow limiter comprises a capillary tube of glass or plastics for example, with a length of about 10 mm and an internal diameter of between about 5 and 50μm, the tube being connected in the supply catheter. By twisting the capillary tube around its longitudinal axis, its capillary flow characteristics can be adjusted, within certain limits, as required. In place of a capillary tube, a supply catheter of adjustable cross-section could be employed as flow limiter.

The device shown in 1 includes an energy source 20 for the pulse generator 9, this source for example comprising a battery, an accumulator, a plutonium capsule or a biological fuel cell. The device also includes a temperature or pressure sensor 21 which, in the event of a temperature change, e.g. because of fever, or a corresponding pressure change in the vapour pressure in the flexible container 2, supplies the pulse generator 9 with a control signal influencing the generator to adiust its supply of control pulses to the flow control valve 8 in such manner as to counteract the effect, on the delivery of fluid to th body, of the change in th vapour pressure in th flexible container 2.

Apart from the programme transmitter 10, which is designed to be carried externally on the body adjacent to the skin 23, for example in a waistcoat pocket or on a belt, the device shown in Figure 1 is designed as an implantable unit. For this purpose, the parts of the device other than the programme transmitter 10 are incorporated in a housing 22 made of a material, for example epoxy resin, which is compatible with body tissue. If necessary, to exclude interference pulses (i.e. pulses other than the control pulses from the control pulse transmitter 11) this housing can be provided with an additional metal layer. By way of alternative, if the programme transmitter 10 is made small enough, it too can be designed to be implanted in the body.

The pulse diagrams shown in Figures 2 and 3 illustrate possible ways in which the flow of medicament through the flow control valve 8 can be controlled as a function of time t. As the flow control valve 8 is alternately switched between its blocking and open conditions by the control pulses applied thereto from the pulse generator 9, successive quantities of fluid pass through the valve as successive flow pulses. The repetition rate and duration of these flow pulses is determined by the repetition rate and duration of the control pulses applied to the flow control valve 8 from the pulse generator 9.

Because of the flow limitation effected by the flow limiter 19, the flow pulses have the same amplitude. The duration T and the amplitude of each flow pulse determine the size of the fluid quantity to which the flow pulse corresponds. The driving force causing the expulsion of successive fluid quantities from the storage container 1 via the flow control valve 8 arises from the fact that the pressure exerted on the fluid in the container 1 by the flexible container 2 remains continuously at a value greater than the fluid pressure at the outlet of the fluid delivery system.

As can be seen from Figures 2 and 3, the dosing of a patient with medicament can be determined at will by suitably programming the pulse generator 9 in regard to the repetition rate and/or duration of the control pulse applied to the flow control valve 8. As indicated in Figure 2, for example, a relatively low daily basic delivery rate B of medicament can be achieved by setting the repetition rate of the control pulses for the valve 8, and thus the flow pulses through the valve, to a low value (pulse interval τ). Without altering the pulse duration, an increased delivery rate Sp of medicament can be achieved by correspondingly increasing the repetition rate of the control pulses and

thus the flow pulses. In the case of Figure 3, a relatively low daily basic delivery rate B of medicament is also achieved by setting the repetition rate of the control pulses for the valve 8, and thus th flow pulses through the valve, to a low value. However, an increased delivery rate Sp is in this case achieved by increasing the pulse duration T. Suitable pulse repetition rates are of the order of between $\frac{1}{4}$ to 3 per minute, while suitable pulse durations are of the order of between 5 and 100 milliseconds.

In a modification of the device shown in Figure 1, the setting of a basic delivery rate of medicament into the body can be effected by means of a further flow limiter, which may for example be formed in corresponding manner to the flow limiter 19 of Figure 1. This will become clearer from Figures 4 and 5, for example.

In Figures 4 to 7, parts corresponding in nature and function to parts shown in Figure 1 are respectively denoted by the same reference numerals and will not be discussed in detail.

The device shown in Figure 4 differs from the Figure 1 device that, in addition to the flow limiter 19 the device includes a flow limiter 24 having an input connected via the expulsion line 6 with the storage container 1 at a point downstream of the flow control valve 8 and having an output connected to the fluid output of the fluid delivery system via the catheter 7. With this arrangement, medicament is continuously delivered into the body via the flow limiter 24 whatever the condition of the flow control valve 8. With the vale in its blocking condition, medicament is thus delivered at a basic rate which is adjustable by adjusting the flow cross-section of the flow limiter 24. For higher delivery rates, the flow control valve 8 is actuated so that medicament is also able to flow into the catheter 7 via the flow control valve 8 and the flow limiter 19.

The device shown in Figure 5 employs a 3/2-way flow control valve 8 in place of the 2/2-way valve employed in the devices shown in Figures 1 and 4. In one condition of the valve, medicament is continuously delivered at a basic delivery rate via the flow limiter 24. In another condition of the valve, medicament is delivered at a high rate via the flow limiter 19.The flow control valve 8 employed in Figure 5 may be controlled in the same way as the corresponding valve in Figures 1 and 4. However, advantageously the device may be provided with position-sensitive switch means which can be arranged on the body to detect different body positions and are arranged to control the flow control valve 8 in dependence upon body position. Such switch means may for example be adapted to detect whether a patient is in a lying position or in a standing or sitting position. Thus, as indicated in Figure 5, th device may be provided with a switch 25, for example a mercury switch (e.g. such as disclosed in German Offlenlegungsschrift 2,106,275) fed by a battery 26. This switch detects whether a patient is in a lying position or in a standing or sitting position and, in accordance with the detected information, switches the flow control valve 8 into the condition for medicament delivery at the basic rate via the flow limiter 24 or at an increased rate via the flow limiter 19.

The devices shown in Figures 6 and 7 have fluid delivery systems which include an auxiliary store 27 connected with the associated flow control valve 8 so as to receive therethrough up to a predetermined volume of fluid from the storage container 1 when the valve is in a first flow condition thereof, and so as to deliver previously stored fluid towards the fluid outlet of the delivery system when the valve is in a second flow condition thereof. The auxiliary store 27 may be a variable-volume vessel of predetermined maximum and minimum volume, in which case the vessel volume is adapted to increase, in opposition to a biasing pressure, when the flow control valve is in its first flow condition and, under this pressure, to decrease when the flow control valve is subsequently switched into its second flow condition, thereby allowing previously stored medicament to be expelled into the body. The variable-volume vessel may for example have an elastic wall portion providing the required biasing pressure or, as illustrated in Figures 6 and 7, the vessel may be provided with a resiliently biased plunger defining or bearing against a displaceable wall portion of the vessel so as to provide the required biasing pressure. However, the auxiliary store 27 may just as well be a constant-volume vessel in which fluid to be stored is compressible to a predetermined pressure such that subsequent decompression of the vessel results in the expulsion therefrom of a corresponding predetermined quantity of fluid. In the case of the device shown in Figure 6, the flow limiter 24 connected between the expulsion line 6 and the catheter 7 allows continuous medicament delivery at a minimum basic daily rate which is adjustable by adjustment of the flow limiter 24. This takes place when the valve 8 is in its illustrated condition, during which time medicament gets stored in the auxiliary store 27. With the valve switched into its other condition, medicament is expelled from the store 27 into the catheter 7 via the valve, thereby allowing an increased rate of medicament delivery. In the case of the device shown in Figure 7, a flow limiter 19 is connected between the

auxiliary store 27 and the catheter 7, this limiter serving to smoothe the expulsion of medicament from the auxiliary store 27, which occurs when the flow control valv 8 is, for the purposes of achieving an increased rate of medicament delivery, switched into its illustrated condition. In its other condition, medicament is delivered at a basic rate via the flow limiter 24 while medicament also gets stored in the auxiliary store 27.

WHAT WE CLAIM IS:—

1. A device for supplying a human or animal body with fluid, the device comprising: a storage container for the fluid; a fluid delivery system for the delivery of fluid from the container into the body via a fluid outlet; and a pressure generator which acts, without an external energy supply, to exert on fluid in the container a pressure sufficient to cause expulsion of fluid from the container into the body via the delivery system, the pressure generator serving to maintain the fluid pressure in the container continuously greater than the fluid pressure at the fluid outlet; the fluid delivery system including (a) a switchable valve openable by the application of control pulses thereto for the periodic release of fluid from the storage container, and (b) a pulse generator for applying to the switchable valve pulses of a predetermined frequency and/or duration for controlling the rate of the periodic release of fluid thereby controlling the peak rate of fluid supplied to the body; the fluid delivery system further including (a) a first flow limiter for controlling the flow of the fluid periodically released by the switchable valve, and/or (b) an auxiliary store for storing and then releasing a predetermined volume of the fluid periodically released by the switchable valve.

2. A device as claimed in claim 1, wherein, for adjustment of the base rate at which fluid is supplied to the body over and above the peak rate, the pulses applied to the switchable valve by the pulse generator are controlled by a predetermined programme corresponding to the required daily dosage of fluid.

3. A device as claimed in claim 1 or 2, wherein the fluid delivery system further comprises a second flow limiter, of preselectable flow cross-section, through which fluid from the storage container can flow to the fluid outlet without passing through the switchable valve, the second flow limiter thereby allowing additional fluid to be delivered to the body at a base rate.

4. A device as claimed in claim 1, 2 or 3, wherein the first flow limiter and, if provided, the second flow limiter is either (a) a supply catheter of adjustable cross-section or (b) a capillary tube connected in a supply catheter the capillary flow characterists of which tube are adjustable by twisting the tube.

5. A device as claimed in any of claims 1 to 4, wherein the auxiliary store is an expandable vessel whose volume increases, as it receives fluid, against a biasing pressure up to a predetermined volume, and whose volume returns to its original value upon release of the fluid received.

6. A device as claimed in any of claims 1 to 4, wherein the auxiliary store is a vessel of fixed volume in which the fluid received is compressed up to a predetermined pressure and from which the fluid received is expelled by subsequent decompression of the vessel.

7. A device as claimed in any of claims 1 to 6, wherein associated with the pressure generator there is a temperature or pressure sensor which, in the event of a temperature variation, counteracts the flow variation which would result by sending to the pulse generator a signal which causes the generator to vary, at a rate inversely proportional to the change in pressure, the time for which the switchable valve is open.

8. A device as claimed in any of claims 1 to 7, including a position-sensitive switch disposable on the body and arranged to control the switchable valve in dependence upon body position.

9. A device as claimed in claim 8, wherein the position-sensitive switch is able to detect whether the patient is (a) in a lying position or (b) in a standing or sitting position, and, in accordance with this information, to cause delivery of fluid to the body via the first flow limiter in the first case and to cause delivery of fluid to the body via second flow limiter in the second case.

10. A device as claimed in any of claims 1 to 9, including a manually operable switch to serve as a programme transmitter for the pulse generator.

11. A device as claimed in any of claims 1 to 10, wherein the pressure generator is a membrane bellows or other flexible container for exerting pressure on the fluid in the storage container, the bellows or other container containing a substance having at body temperature a superatmospheric vapour pressure of up to 3 bars.

12. A device as claimed in claim 11, wherein the substance is chloroethane, a fluorinated alkane, or a fluorinated and chlorinated alkane.

13. A device as claimed in any of claims 1 to 12, the device being arranged in a unit which is implantable in the body.

14. A device as claimed in any of claims 1 to 13, including a programme transmitter for controlling operation of the pulse generator in accordance with a preselectable programme.

15. A device as claimed in claim 14, wherein the programme transmitter is implantable in the body or adapted to be carried externally on the body.

16. A device as claimed in claim 14 or 15, wherein the programme transmitter includes (a) a programme store having a timing device and a programme introduction device for introducing time or switching-frequency information, (b) an information transmitter for indicating the prevailing programme stage and the time, and (c) an optical or acoustic signal transmitter.

17. A device for supplying a human or animal body with fluid, substantially as hereinbefore described with reference to Figures 1 to 3, Figure 4, Figur 5, Figure 6 or Figure 7, of th accompanying drawings.

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Printed for Her Majesty's Stationery Office by Burgess & Son (Abingdon), Ltd.—1978.
Published at The Patent Office, 25 Southampton Buildings, London, WC2A 1AY
from which copies may be obtained.

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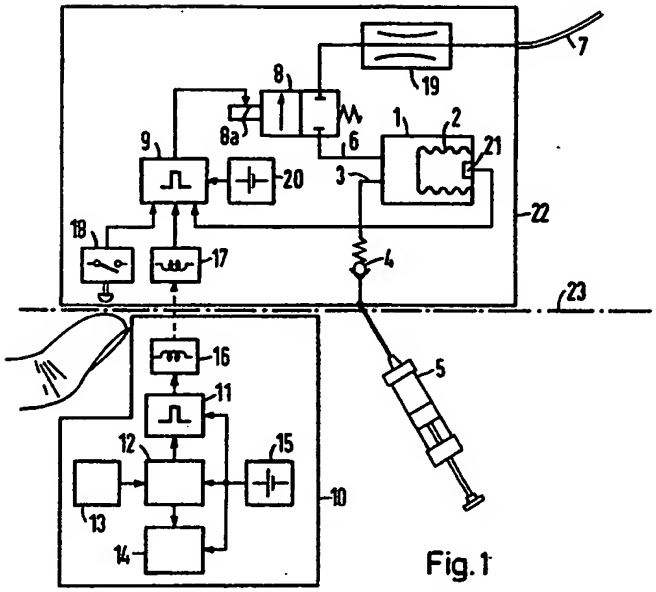

Fig. 1

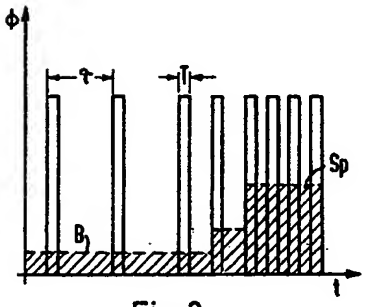

Fig. 2

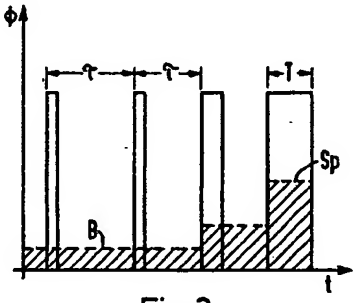

Fig. 3

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COMPLETE SPECIFICATION

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Sheet 2

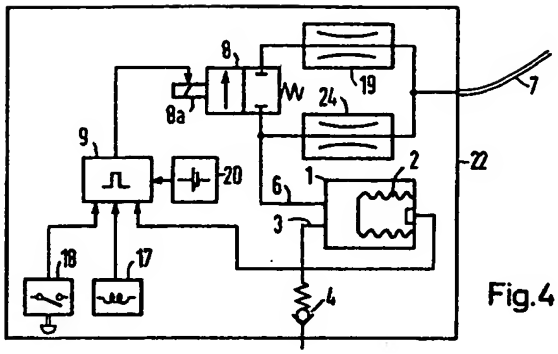

Fig.4

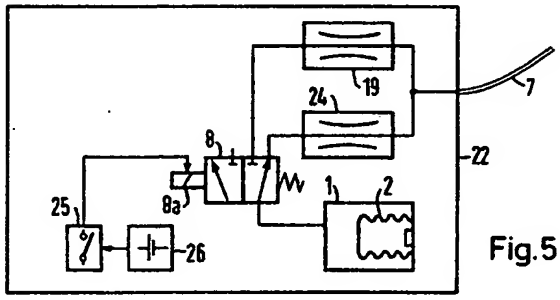

Fig.5

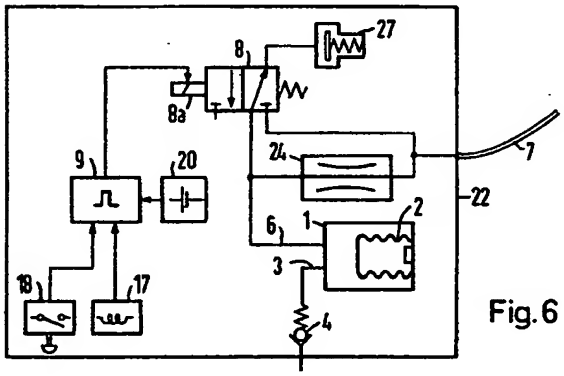

Fig.6

1506305 COMPLETE SPECIFICATION
3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 3

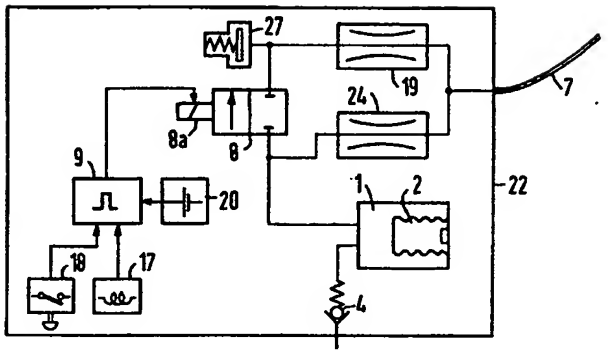

Fig.7